Chemosphere 181 (2017) 9–18

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Review

Geosmin as a source of the earthy-musty smell in fruits, vegetables and water: Origins, impact on foods and water, and review of the removing techniques

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HIGHLIGHTS

- Geosmin as a source of the earthy-musty smell in foods and water.
- Geosmin is difficult to be removed from fruits, vegetables and water.
- Need to understand the causes and to find solutions to eliminate geosmin.

ARTICLE INFO

Article history:
Received 12 January 2017
Received in revised form
1 March 2017
Accepted 8 April 2017
Available online 8 April 2017

Handling Editor: Xiangru Zhang

Keywords:
Geosmin
Off-flavor
Earthy-musty
Vegetables
Water
Removal

ABSTRACT

The earthy-musty smell produced by *Streptomyces* sp. is assigned to geosmin and is responsible for the major organoleptic defects found in drinking water, fruits and vegetables such as grapes, mushrooms, carrots, and beet. Geosmin is also found in juices and musts before fermentation and its presence has been associated with partial presence of *Botrytis cinerea*. It has a variable detection threshold depending on the matrix and the detection level ranges from 5 to 50 ng/L. On the sensory level, very few individuals are immune to geosmin and although the intensity of the defect caused by this molecule decreases rapidly in the nose, a bad taste is very persistent in the mouth. As the origin of geosmin is fungal, conventional control techniques used for geosmin prevention are limited to ventilation, improving the integrity of plants and use of storage temperatures around 1 °C in a humidity-controlled environment. However, it has been demonstrated that only the combination of different prophylactic and preventive measures provide a relatively sufficient efficacy. Therefore, prevention of factors favoring the formation of geosmin is still topical. Some chemical treatments showed relatively good results against *Botrytis cinerea*. However, there is a requirement that must be met, namely that only one chemical per family per year must be used. Moreover, a multi-year alternation of chemical families is a strong agronomic recommendation. Regarding *Penicillium*, no active material is 100% approved and it negative effects plants such as beet and grapes. Consequently, the importance of finding effective ways to fight against geosmin formation is still relevant. From analytical point of view, measurement of geosmin is mainly based on gas chromatography.

Contents

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http://dx.doi.org/10.1016/j.chemosphere.2017.04.039
0045-6535/

Abbreviations

IUPAC	International Union of Pure and Applied Chemistry
WTP	water treatment plant
UV	ultraviolet photolysis
PDS	potassium peroxydisulfate
t-BuOH	*t*-butyl alcohol
DO	dissolved oxygen
Biodegradation	active biofilm-associated bacteria
AC	active carbon

1. Introduction

In the 19th century the odor of the soil in the forest after the rain was introduced for the first time. The found substance, geosmin (GSM) (Fig. 1), had *earthy* and *musty* smell characteristics (Gerber, 1967). The same molecule of GSM subsequently has been found in many other places (drinking water, various fruit and vegetables), even after all kinds of industrial processing treatments (Parinet, 2010). However human nose is extremely susceptible to GSM and have very low levels of odor threshold (from 6 to 10 ng/L), customer complaints normally start at 7 ng/L at 45 °C (Omur-Ozbek et al., 2007). Although GSM have no public health concern the occurrence of objectionable tastes and odors in potable water supplies and food products has been recognized as a global problem (Acree et al., 1976; Buttery and Garibaldi, 1976; Pirbazari et al., 1992; Bláha et al., 2004). Thus, the economic impacts associated with "off-flavors" have encouraged research into the bioregulation of GSM synthesis and elimination (Christopher, 1993). The molecules of GSM is an odorous secondary metabolite produced during growth by various microorganisms such as cyanobacterias (Saadoun et al., 2001; Giglio et al., 2008; Lin et al., 2009; Jahnichen et al., 2011), actinomycetes (Gerber, 1967; Ishibashi, 1992; Carpenterboggs et al., 1995; Lee et al., 2011), protozoa (Hayes et al., 1991; Parinet, 2010), molds (Borjesson et al., 1993; Larsen and Frisvad, 1995; Schnürer et al., 1999) and fungi (Darriet et al., 2000; Dickschat et al., 2005; La Guerche et al., 2005). A bulk of GSM is retained in the cells of microorganisms, the liberation of GSM from the cells could be performed in case of rupture physical processes such as grazing or treatment (Gill, 2006; Parinet, 2010).

According to IUPAC the molecule of GSM is isoterpenoid named as (4S,4aS,8aR)-4,8a-Dimethyl-1,2,3,4,5,6,7,8-octahydronaphthalen-4a-ol, another name is trans-1, 10-dimethyl-trans-9-decalol (Fig. 1). It represents neutral oil with an approximate boiling point of 270 °C, which contains carbon and hydrogen, but no nitrogen. It was found that the reaction with acid gives odorless neutral oil (argosmin), with boiling point around 230 °C (Gerber, 1967). Other properties like refractive index (1.4650 ± 0.0029 CL), density (0.9494 ± 0.0127 g cm^{-3}), aqueous solubility (150.2 ± 4.1 g L^{-1}), octanol/water partition coefficient (3.70 ± 0.03 CL) and Henry's law constant ($6.66.10^{-5}$ atm m^3 mol^{-1}) were determined as well (Pirbazari et al., 1992).

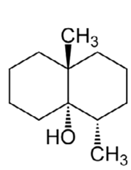

Fig. 1. The molecular structure of geosmin (trans-1, 10-dimethyl-trans-9-decalol).

The aim of the present review is to highlight the problems associated with geosmin as a source of the earthy-musty smell in fruit, vegetables and drinking water. The present study presented the most used techniques to remove geosmin ones it occurred in different products. The need for novel, highly effective preventing methods to avoid geosmin formation in fruit, vegetables and drinking water is also highlighted.

2. Biosynthesis pathway of geosmin

The production of GSM is not yet well understood, as well as factors that influence GSM production by microorganism. Temperature (Saadoun et al., 2001; Watson et al., 2003), light intensity (Tsuchiya and Matsumoto, 1999; Saadoun et al., 2001), availability of the nutrients (iron, nitrogen, phosphorus, copper etc.) (Wu et al., 1991; Dionigi et al., 1992; Saadoun et al., 2001) and interactions between bacteria (*quorum sensing*) (Zaitlin and Watson, 2006) seem to have an impact on the production of these odor molecules. In addition the metabolism and the biosynthetic pathway has not yet been fully elucidated (Gill, 2006). However biosynthetic pathway of GSM recently has received considerable interest (Jüttner and Watson, 2007). Much progress in the knowledge has been made by Bentley and Meganathan in their experiments with Streptomyces (Bentley and Meganathan, 1981).

Such biosynthetic pathways as mevalonate (MVA) and the methylerythritol (MEP) (also called the non-mevalonate) deserve particular interest (Fig. 2A, B). It is known that the GSM molecules are a terpenoid metabolites derived from isoprenoid. Isopentenyl diphosphate (IPP) is the central intermediate in the isoprenoid biosynthesis and could be produced via two possible MVA and MEP pathways (Lange et al., 2000; Gill, 2006). It should be noted that alternative routes of entry of pentose phosphate -cycle substrates derived from photosynthesis rather than entry from glycolysis (Fig. 2C) was supported by radiolabeling experiments with Synechocystis sp (Ershov et al., 2002). It is also worth to note, that few microorganisms (Eubacteria) could also produce farnesyl diphosphate from IPP and germacradienol (1(10), 4-germacradien-11-ol) that subsequently leads to the final GSM formation (Gust et al., 2003; Jiang et al., 2007; Jüttner and Watson, 2007; Jiang and Cane, 2008).

Although the actinomycetes are generally considered as the main causes of the GSM formation, other microorganisms such as cyanobacteria and fungi, have also been proposed as being responsible for GSM formation (Watson et al., 2003; Parinet, 2010). It should be noted that no constant correlation has been found between GSM concentration and microorganism population via the intensity of the odor. Besides the culturing of microorganism on the nutrient medium may induce the atrophy of GSM production (Zaitlin and Watson, 2006).

The studies on the behavior of actinomycetes in the different compositions of medium showed that microorganisms could